OPTIMIZED WORKFLOW AND VALIDATION OF CARCASS CT-SCANNING

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***Abstract*— An optimized workflow for CT scanning of pig carcasses is presented, including real time validation of images (tomograms); automated tissue assesment and cutting into primals. Advanced image analysis (PigClassWeb) facilitates the definition of virtual cuts in a reference pig. These cuts are automatically propagated to the whole population of pigs that are scanned, in such a way that the virtual cuts are anatomically similar for each carcass, irrespective of size, weight and proportions. The ability to estimate very accurately the weight of arbitrary cuts provides information about the yields of the cuts on the population as a whole, as well as on each scanned carcass. The user can access the application through a simple web-browser, adjust the settings of a specific cut through a view of the scanned reference carcass. For the simpler type of cuts the results are ready within seconds, when applying the cut on the whole population. PigClassWeb is scalable in the sense that future scans automatically are processed and included in the "Population of Virtual Pigs".**

***Index Terms*—Automated image analysis, CT, Grading, Landmark, LMP, Validation, Workflow, Yield**

I. INTRODUCTION

Determination of the commercial value of a porcine carcass is often based on an estimated weight of the lean meat content relative to the total weight of the carcass. Within the EU the Lean Meat Percentage (LMP) is a highly regulated parameter of any carcass delivered to the abbattoir as the parameter is influencing the payment to the producer.

The LMP is estimated from an online (indirect) measurement performed on the warm carcass on the slaughter line. The indirect methods, based on various modalities, optical probes, vision or ultrasound systems, are calibrated to a reference which is a manual dissection, in a quite comprehensive experiment including a heavy use of dissection experts.

Fig. 1. An automated cutting line. The half carcass is cut into three primals: Ham, Middle and Shoulder.

Recently including an intermediate step in the calibration trial has been allowed by the Commission and some trials including CT scanning has been approved (Judas (2006)). In large experiments, inevitably procedual errors from operators, measurement hardware aso. may occur. On site validation of the CT scanning therefore is an advantage to ensure the final data quality of the experiment. The calibration trial validated three convertion factors between volume and weight, enabeling the potential of estimation of the weight of a virtual (final) product, based on scanning of the raw material, i.e. a Danish half carcass.

We have designed a workflow to cope with the challenges of scanning validation, automated image handling and partitioning of the half carcass into three primals. The workflow reduce the cost of such a trial as most of the scanned carcasses may be returned to production with very little loss for the abbattoir. After the validation the images are uploaded into a database using an upload client. In the database the automatic analysis is initiated: removal of the scanning table, segmentating any separated part still belonging to the carcass (e.g. separated tenderloin) and doing the tissue assessment into three classes: lean meat, fat and bone. The algorithm for the assessment, described in (Vester-Christensen (2008)), is based on a contextual strategy. The database forms a "catalogue" of the Danish pig population. The members of the catalogue is registered to one single, average "atlas-pig", representing the population through the transformation to each individual. Furthermore, simple cutting procedures in the atlas-pig may be transferreded to any member of the catalogue (Fogtmann Hansen (2009). Anatomically determined cutting positions in one individual may be transformed to all other members by registration, Even future members may be added to the catalogue by registration to the atlas-pig.

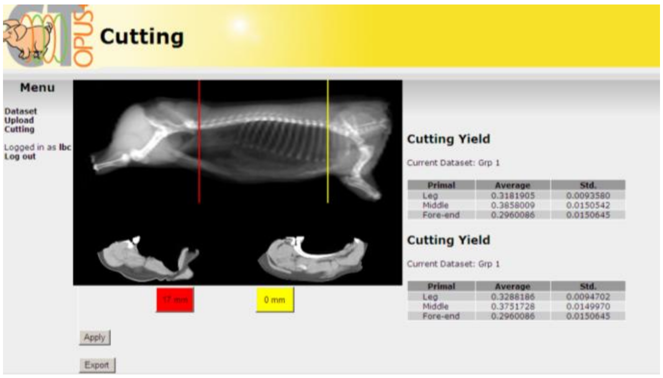

Fig. 2. The PigClassWeb. The automated algorithm cuts each of the aligned carcass in the dataset into three primals. The cutting lines are shown in red and yellow and the yield is calculated for each carcass. The average value is displayed in the screen.

As the carcass is scanned on the patient table, any anatomic part may be placed slightly different, thus referring to any anatomic feature of the carcasses will vary slightly in the reference system of the images. The automatic analysis therefor aligns all image stacks to mimic the position of the carcass on a Danish primal cutting station, thus improving the performance of a automatic virtual primal cutting process, so evaluation of the (virtual) yield of the three primals can be made. The nominal position of the saw blades is found relative to 4 anatomic landmarks; and alternative cutting lines may be simulated to estimate the primal yield of alternative cuts.

As the hind foot often is present in experiments for ease of handling the extremity must be handled by the automatic assessment software as the foot do not contribute to a standard carcass evaluation.

II. MATERIALS AND METHODS

The validation is made on a selection of standard Danish carcasses to compare an expert selection of anatomical landmarks to the performance of an atlas based automated algorithm. 6 landmarks are selected: 2 for alignment of the carcass, 2 for identification of the primal cut positions and furthermore 2 for cutting off the hind foot.

Validation without a reference (true position of the landmarks) is handled by triplicate expert selection of the six points, the selection is assumed to be independent as object ID is unknown and presented randomly

The uncertainty of the expert is found from the difference between two repeated selections of the landmarks. This is not possible for evaluation of the algorithm as repeating the algorithm results in identical potentially erroneous results. We estimate the uncertainty of the algorithm from the distribution of the difference between the result made by the algorithm and the average of the three repetitions of the expert.

A. Materials

The randomly selected sample of pig carcasses (26 individuals) is chosen from a commercial abattoir. The sample is scanned approximately 24 hours after bleeding. The scanning was made using the following protocol settings: Standard reconstruction, 140kV, 80mA, 0.9x0.9x10mm voxel size, axial scanning.

Before scanning the carcasses are prepared according to the EU recommendation except for leaving the hind foot on the carcass and the prepared carcasses are weighed on a calibrated industrial scale.

B. Validation of scanning

For improving the quality of the experimental dataset an automatic estimation of the carcass weight is made before the carcass is taken back to production, either chilling (first scan) or primal cutting (second scan). The estimation is made by automatic version of the PigClass software (Vester-Christensen (2008)). adapted to run on a parallelized Linux computer (PlayStation3) In case of difference between the simulated and scale weight a warning is given to the operator in order to correct any detail in the dataset, like mistyping, missing images or missing anatomical parts (e.g. the tenderloin).

C. Uploading of data

The validated data is uploaded either individually or batch wise to the database server using an Upload client. The client offers a possibility to correct information like sample ID, name or scale weight, vital for the quality of the final data set.

D. Automatic handling

PigClassWeb is an automatic framework for handling image stacks of CT scanned carcasses. The framework forms the base of the database server performing the following subtasks:

- Removal of the patient table
- Assessment into three classes
- Alignment of carcass
- Removal of hind leg
- Tenderloin and jowl handling

The framework is based on semiautomatic software described elsewhere (Vester-Christensen et al.(2009)). The extension compared to previous versions is the carcass alignment and removal of the hind leg. This function is based on the position of 6 anatomical landmarks. 4 points are used to align the carcass and identify the primal cut position and the remaining two points at Tibia and head of Tuber Calsis are used to cut off the hind foot in the joint.

1. Top of aitch bone
2. Top of 1. neck joint
3. Ham point
4. Fore knuckle

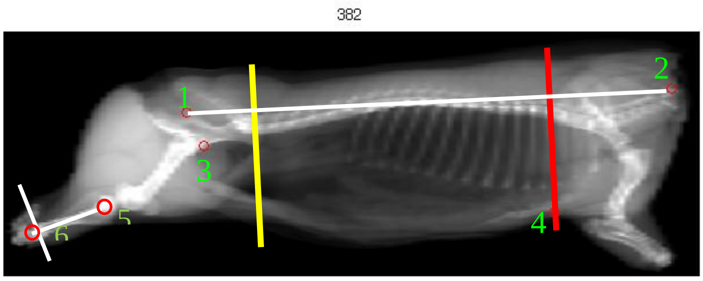

Fig. 3. The six points used for aligning the carcass (1+2), defining the primal cutting lines (3+4) and cutting off the hind foot (5+6).

Following this process the aligned carcass is ready for a virtual primal cutting process. The validation of the automated annotation of landmarks by the software algorithm is compared to a manual selection performed by an expert.

The validation of the automated annotation of landmarks by the software algorithm is done by comparing the error (variance) of the algorithm to the error (variance) of a human expert. Since the true landmarks are not known the errors cannot be computed directly. Computing the distribution of the difference between two human expert annotations reveals the average human expert variance. Furthermore computing the distribution of the difference between the algorithm and the average human expert, enables the estimation of the error of the algorithm. The details of this procedure are described in Ólafsdóttir et al (2007).

E. Yield of primal cuts

Primal cutting at the selected positions as shown above is made automatically as part of the import process to the data base. The yield of the three important primal cuts: ham, middle and fore-end is calculated with the nominal position of the virtual cutting lines. The yield based on the expert selected points is compared to the corresponding yield based on the points selected by the algorithm.

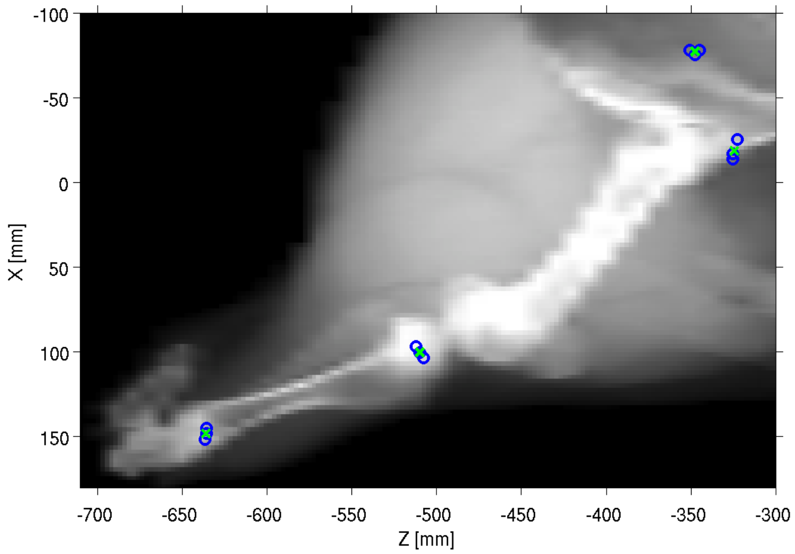

Fig. 4. Example of the triplicate annotation (blue rings) by the expert of four of the landmarks 1, 3 5 and 6 as indicated in Fig. 3.The crosses (the average expert) are used as input to the automated algorithm.

III. RESULTS AND DISCUSSION

The landmarks are identified in the topograms as shown in Fig. 4.

The position of the landmarks (x,y) are measured in absolute coordinates. The annotation of landmarks 1 through 4 by the automated algorithm is compared to triplicate annotations by the expert.

Table 1.	1 (top of aitch bone)	2 (top of neck joint)	3 (ham point)	4 (fore knuckle)
Expert std. dev..	**3.5 mm**	**3.2 mm**	**4.7 mm**	**8.2 mm**
Algorithm std. dev.	**3.9 mm**	**6.6 mm**	**3.5 mm**	**6.6 mm**
Expert vs. mean expert difference	0.61 mm	0.75 mm	1.3 mm	1.3 mm
Mean algorithm vs. mean expert difference	1.4 mm	1.4 mm	-1.7 mm	-0.21 mm
p-value (t-test: mean of algorithm =? mean of average expert)	0.027	0.14	0.0097	0.85

The only (***) significant discrepancy between average expert and algorithm is found for the ham point.

The annotated landmarks are then used in estimation of the nominal yield of the three primal cuts: Ham, Middle and Shoulder.

The expert points (average of all three annotations) are used to control the position of the cutting lines (yellow and red in Fig. 3). The "expert-yield" is compared to the atlas based algorithm and expressed as mean difference and standard deviation.

Table 2.	Ham	Middle	Shoulder
Mean difference	-2.3g	-2.7g	5.0g
Rel. mean difference	-0.71%	-0.73%	1.6%
Standard deviation	2.8g	8.3g	6.8g

The mean difference between expert and atlas based yield is quite small with the shoulder/middle cut showing the highest deviation of 1.6% between expert and algorithm. This is assumed to be due to the quite high deviation in expert and atlas annotation of point 4 at the fore-knuckle.

IV. CONCLUSION

It is concluded that the atlas based algorithm is sufficiently accurate to be used for simulation of nominal yield of the primal cutting process shown in Fig 1. This furthermore opens to simulate different primal cutting lines in order to investigate alternative applications of the carcass. One example is shown in Fig. 2 where the nominal cutting is compared to a cut, producing a larger ham primal, 17 mm longer on average and approximately 1% more of the total carcass weight in the ham primal.

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